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NEURAL BASES OF MUSIC AND ITS IMPACT ON MUSIC THERAPY: A LITERATURE REVIEW

Bases neuronales de la música y su impacto en la musicoterapia: revisión bibliográfica

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ABSTRACT

Background. The interplay between music and the brain has been examined for nearly a century; yet practice-oriented knowledge remains scattered and unsynthesised. **Objectives.** To critically review the neural foundations of music and provide evidence-based guidance for music-therapy practice. **Methods.** A PRISMA-compliant literature review was undertaken. Searches in PubMed, Dialnet, Google Scholar and SciELO produced 75 records; after screening, 45 studies published between 1936 and 2024—17.78 % within the last decade—were included silvia y cristinasilvia y cristina. The strategy combined the Boolean operator "music AND brain" in English and Spanish, and titles and abstracts were independently screened; data extraction followed a standardised protocol silvia y cristina. Design, participants and outcomes were narratively synthesised through the four PRISMA phases. **Results.** Evidence converges on coordinated activation of auditory, limbic and motor networks during musical perception, while musical training drives cortical plasticity and structural change, including enlargement of the corpus callosum silvia y cristina. Only five included papers used controlled experimental designs. Post-2020 gaps persist in studies employing multimodal neuro-imaging and cutting-edge technology silvia y cristina. Findings also underline music's modulation of emotional circuitry and cognitive networks implicated in language and executive functions. Heterogeneity in samples and protocols still hampers cross-study comparison. **Conclusions.** Current evidence supports the clinical and educational integration of music, yet longitudinal, technology-enhanced studies (fMRI, PET, MEG) are urgently required to clarify short- and long-term benefits and to define target populations silvia y cristina. This synthesis provides an updated neuroscientific framework to inform rigorous music-therapy implementation.

Keywords: music, brain, brain function, neurology, hearing.

RESUMEN

Introducción. La relación entre música y cerebro se investiga desde hace casi un siglo; las revisiones previas presentan dispersión metodológica y carecen de un enfoque integrador orientado a la musicoterapia. **Objetivos.** Revisar críticamente las bases neuronales de la música y derivar orientaciones para la intervención musicoterapéutica. **Método.** Se realizó una revisión bibliográfica conforme a PRISMA. Cuatro bases de datos (PubMed, Dialnet, Google Académico, SciELO) arrojaron 75 registros; tras cribado y exclusión, se analizaron 45 estudios publicados entre 1936 y 2024, el 17,78 % fechados en la última década silvia y cristinasilvia y cristina. El proceso siguió las cuatro fases estándar de identificación, cribado, elegibilidad y síntesis; se extrajeron diseño, participantes y hallazgos y se sintetizaron de forma narrativa. **Resultados.** Los artículos convergen en que la percepción musical activa redes auditivas, límbicas y motoras, y que el entrenamiento musical induce plasticidad cortical y cambios estructurales —p. ej., aumento del cuerpo calloso— silvia y cristina. Solo cinco trabajos emplearon diseños experimentales controlados. Persisten vacíos posteriores a 2020 en estudios con neuroimagen multimodal y tecnologías emergentes silvia y cristina. La heterogeneidad de muestras y protocolos limita la comparación inter-estudios. **Conclusión.** La evidencia avala la integración clínica y educativa de la música, pero urge abordar preguntas específicas mediante diseños longitudinales y técnicas avanzadas (fMRI, PET, MEG) para clarificar beneficios a corto y largo plazo y precisar poblaciones diana silvia y cristina. Esta síntesis ofrece un marco neurocientífico actualizado que orienta la aplicación rigurosa de la musicoterapia.

Palabras clave: música, cerebro, función cerebral, neurología, audición.

INTRODUCTION

This literature review stems from a need to explore existing research that deepens our understanding of the music-brain dichotomy. Specifically, it investigates the biological components involved in the auditory process, alongside the physiological, psychological, and emotional responses that music elicits in individuals.

Storr (2002) posits that "music has always been present in our lives, we always find it, even if we do not seek it" (p. 65). Sacks (2007) further elaborates on this perspective, asserting that music is an inherent aspect of human existence, enjoyable regardless of an individual's musical knowledge or cultural background.

Thus, the primary objective of this review is to define the neural decoding of musical sound messages in individuals, their responses to these messages, and the distinctions between such responses. To this end, we will delve into the functioning of human auditory and neural processes, observable differences and similarities in this processing, and the resulting responses.

The specific objectives derived from this main aim are as follows: to ascertain whether the decoding of sound events is uniform across all human beings; to identify potential factors leading to variations in the decoding of sound events; and to explore the diverse emotional and psychological responses to the same musical stimulus.

The Auditory System

According to Astete-Cornejo and Collantes-Luna (2022), audition is one of the most vital senses enabling living beings to interact with their environment. Furthermore, García-Porrero and Hurlé (2020) state that, for humans, the significance of audition lies in its role in comprehending intrinsically human actions, such as verbal language and music. In other words, many scientists study the auditory event and its subsequent processing due to the human capacity to produce and comprehend complex sounds, as evidenced by a plethora of studies (Domínguez et al., 2023).

The functioning of the auditory system involves various biological areas, categorised into peripheral and central structures (Peterson et al., 2023). Broadly, peripheral auditory receptors decompose complex sounds into simple frequencies, which are then transmitted to the Central Nervous System (CNS), thereby engaging parts of the cerebral cortex in auditory processing (Domínguez et al., 2023).

Peripheral Auditory System

Firstly, the Peripheral Auditory System comprises three main sections: the external ear, which includes the auricle and the external auditory canal; the middle ear, containing the auditory ossicles and the tympanic membrane; and the inner ear, formed by the semicircular canals, the vestibule, and the cochlea (Conejo et al., 2021).

Regarding the external ear, Merino and Muñoz-Repiso (2013) highlight a dual function of the auricle: it amplifies sound waves gathered from the environment and discerns the location of the sound source. Sound waves penetrate the external auditory canal until they reach the tympanum (Lalwani, 2018) in the middle ear. The interaction of sound waves with the tympanic membrane causes it to move, transforming into vibrations as it is transmitted to the ossicular chain: the malleus, incus, and stapes (Peterson et al., 2023). The oscillations of the stapes footplate generate a pressure change in the inner ear, which is filled with a fluid called perilymph, propelling a wave along the basilar membrane of the cochlea (Lalwani, 2018).

In this respect, it is pertinent to examine the cochlea, a membranous tube located within the bony labyrinth. It features three walls, with the inferior wall, the basilar membrane, being particularly notable as it houses the receptor cells of the organ of Corti (García-Porrero and Hurlé, 2020). In essence, the vibrations of sound waves are conducted by the ossicular chain until they reach the liquid medium (perilymph). This causes the basilar membrane, where the acoustic receptor is situated, to vibrate (García-Porrero and Hurlé, 2020).

Central Auditory Nervous System (CANS)

As for the Central Auditory Nervous System (CANS), understanding the definition of Central Auditory Processing (CAP) is crucial. According to Griffiths (2002), Central Auditory Processing, known as CAP, refers to the mechanism by which complex sounds are analysed after their transformation from acoustic to neuronal energy in the cochlea. This process results in an auditory pattern that enables discrimination, identification, localisation, and integration of information (De Bonis and Moncrief, 2008). Furthermore, Zenker et al. (2007) state that this process precedes semantic processes, i.e., the assignment of meaning to the information.

Regarding how and where CAP occurs, the acoustic pathway is of paramount importance. According to García-Porrero and Hurlé (2020), this is "the set of neurons that conduct nerve impulses originating in the receptor cells of the organ of

Corti to the auditory cerebral cortex" (p. 254). Therefore, the acoustic pathway is responsible for the selection, analysis, and decoding of auditory information, as well as for formulating a response (Martínez and Jiménez, 2017).

Stages of the Acoustic Pathway

Following Martínez and Jiménez (2017), the acoustic pathway can be differentiated into three parts based on their respective functions. These authors delineate the conductive part of the acoustic pathway, comprising the external and middle ear, which is responsible for collecting sound impulses. Subsequently, the sensory-perceptive zone is found in the inner ear, where mechanical energy is transformed into electrical energy or neural activity. Finally, the acoustic pathway includes a neural zone where the electrical energy is analysed.

Moreover, various abilities are engaged during this process, facilitating the processing of information until it reaches the auditory processing areas of the brain (Martínez and Jiménez, 2017). As per Cañete (2006) and Martínez and Jiménez (2017), these abilities include: auditory attention (attentional ability to auditory stimuli), auditory localisation (ability to pinpoint the sound source), auditory discrimination (ability to differentiate between sounds), temporal aspects (ability to detect temporal features of sound stimuli), auditory association (ability to associate a sound with its source and/or a specific situation), auditory performance in competitive acoustic signals (ability to discern sounds masked by background noise; i.e., the detection of independent stimuli presented simultaneously), auditory performance in degraded acoustic signals or auditory closure (ability to comprehend a complete word even when information is missing), and auditory memory (ability linked to the storage, recall, and recognition of auditory stimuli).

Neural Adaptation

In this regard, it is noteworthy that, generally, neural adaptation in the Nervous System is associated with a decrease in responses to stimuli repeated over time (Camello, 2018). In response to this, Aedo-Sánchez (2023) classifies adaptive neural responses into two groups: specific adaptation (a decrease in neural responses to frequent stimuli) and neural habituation (a generalised reduction in neural discharge, as per Pérez-González and Malmierca, 2014).

Thus, depending on the reiteration of stimuli, the neural responses of the Nervous System can decrease or increase, a phenomenon known as specific adaptation (Aedo-Sánchez, 2023). In the presence of certain auditory incentives, the Central Auditory Nervous System (CANS) can make predictions based on previous experiences, a concept termed predictive coding theory (Aedo-Sánchez, 2023).

Auditory Processing Regions of the Brain

Continuing with the brain regions involved in auditory processing, the Auditory Cortex is the area of the cerebral cortex linked to hearing. According to Domínguez et al. (2023), Paul Broca (1824-1880) and Carl Wernicke (1848-1904) conducted the initial studies on the auditory cortex, associating it with auditory perception and language. However, González's (2020) definition elucidates the function of the auditory cortex concerning music. In her words: "the auditory cortex allows us to differentiate between various tones and to feel varied rhythms; however, music is such a complex stimulus that it is actually processed by many areas of the brain" (González, 2020, p. 7). Furthermore, according to García-Porrero and Hurlé (2020), the auditory cortex is subdivided into two distinct areas: the primary receptive auditory area and the secondary or higher processing area.

The primary receptive auditory area, also known as the Primary Auditory Cortex (PAC) according to Domínguez et al. (2023), is responsible for receiving coarse or undifferentiated auditory stimuli such as noises, hums, whispers, etc. (García-Porrero and Hurlé, 2020). Notably, this area possesses a tonotopic representation map (frequency projection) of sound, meaning that high frequencies are received in the posterior part of the area, and low frequencies in the anterior part (García-Porrero and Hurlé, 2020). In other words, the PAC has a series of activation bands that involve the distribution of sound frequencies (Domínguez et al., 2023). Finally, it is important to mention that, according to García-Porrero and Hurlé (2020) and due to the crossing over of the acoustic system, the PAC receives approximately 60% of information from the contralateral ear.

The secondary or higher processing auditory area has a more complex structural and functional nature than the primary area, as it is involved in the identification and recognition of information (García-Porrero and Hurlé, 2020). According to Javad et al. (2014), this area is more active in analysing sound parameters such as species-specific responses, threshold, and auditory memory.

Furthermore, García-Porrero and Hurlé (2020) infer that one of the functions of this area in both cerebral hemispheres is to recognise sound stimuli that require a reaction and are not linked to music and/or language. They also suggest that the secondary area of the right hemisphere is responsible for recognising musical rhythms and melodies. Despite this, both authors emphasise that 95% of the secondary area is dedicated to language comprehension, with an asymmetric representation of sounds in the human brain.

The Brain's Response to Music

Given the above, audition is a mechanism that involves perceiving vibratory stimuli decoded in the brain. Therefore, it is important to delve into the events within the Central Auditory Nervous System (CANS) as vibratory waves are transformed (Astete-Cornejo and Collantes-Luna, 2022).

Music, in the words of Arias (2014), "can be considered a special type of language which, in addition to communication functions—especially emotional—has artistic and cultural facets" (p. 149). It is therefore not surprising that its auditory processing differs from that previously explained. Like other sound stimuli, music enters through the auditory canal to the cochlea, where the vibration of the basilar membrane converts musical waves into electrical activity (Talero et al., 2004; Koelsch, 2005). Subsequently, the processing of the acoustic signal results from the analysis of musical pitch, timbre, and intensity (Sinex et al., 2003; Langer and Ochse, 2006). According to Arias (2014), this analysis, along with the perception of rhythm and formal aspects, would be a function of the left hemisphere; while the right hemisphere is linked to the innate musical phenomenon, melody, and timbre.

Acoustics is the branch of physics that studies pressure waves, the sound-generating waves (Merino and Muñoz, 2013). According to Arias (2014), sounds are composed of one or more tones, which are the result of a specific number of vibrations. The characteristics of these vibrations determine the analysis of sound parameters: the number of vibrations per second determines the pitch of the sound (a higher number of vibrations results in a higher perceived sound); the mass of the vibrating body and the amplitude of its vibration determine the sound's intensity; and timbre results from the combination of the fundamental tone originating the vibration and its associated frequencies (Arias, 2014).

Continuing with the processing of music, when a musical sound stimulus is received, each frequency activates a specific point on the basilar membrane. This allows for the analysis of received musical information based on which nerve endings were excited and with what intensity (Muñoz and Merino, 2013). Thus, according to Muñoz and Merino (2013), the pitch of sounds can be determined in two distinct ways: by the excited point on the basilar membrane, and by the periodicity of the vibrations (their frequency).

Brain Areas Involved in Musical Processing

Regarding the brain areas linked to musical processing, an interest in understanding how this occurred in individuals emerged in the 1990s (Martínez, n.d.). Thanks to technology and existing knowledge about sound components, it was possible to conduct functional imaging studies that demonstrated the involvement of both hemispheres during music processing (Pantev et al., 1998; Altenmüller, 2001), thereby rectifying the notion that the right hemisphere was exclusively responsible for this processing (Levitin, 2006). For example, the right hemisphere was attributed the capacity to perceive melodies (Kimura, 1964); however, Bever and Chiarello (1974) demonstrated that their processing occurs bilaterally, i.e., in both hemispheres.

Therefore, the right hemisphere is responsible for processing, recognising, and discriminating timbre and pitch (Evers et al., 1999; Tramo, 2001), as well as musical memory, intonation, and tonal memory (Loring et al., 1992; Liégeois-Chauvel et al., 1998). Conversely, the left hemisphere, exclusively associated with language recognition and processing (Binder et al., 2000; Hickok and Poeppel, 2000), undertakes the recognition of rhythmic and sequential structures (Platel et al., 1997; Andrade and Bhattachary, 2003).

Music impacts various brain areas (Lozano et al., 2013). Consequently, Custodio and Cano-Campos (2017) synthesised the brain regions implicated in listening to music: the rostromedial prefrontal cortex, responsible for the emotional aspect of music as activated by tone and rhythm; the right temporal lobe, which handles basic sound processing; and the limbic system, through its communication with memory-related areas.

Lozano et al. (2013) suggest that reward and pleasure centres are involved in music processing. Indeed, Castrillo (2020), who studied the phenomenon of piloerection, affirmed that listening to music releases dopamine, a neurotransmitter linked to pleasure. In her own words: "the greater the emotional intensity a song or melody causes, the greater the release of dopamine and, therefore, the greater the pleasurable sensation X̄ will provoke" (Castrillo, 2020, p. 34).

Salimpoor et al. (2011) conducted a study on dopamine release during music listening. Following musical audition, researchers recorded brain activity using functional magnetic resonance imaging (fMRI) equipment, yielding the following results: dopamine release occurs upon listening to a preferred melody and in anticipation of hearing it (Salimpoor et al., 2011). Palacios and Olaya (2023) indicate that musical listening also leads to the release of endorphins, hormones that provide feelings of well-being, pleasure, and, in turn, decrease pain perception. This assertion is supported by a study by Hernández Troya (2022), which highlights the release of endorphins and natural opiates as benefits of music.

The Impact of Musical Training

For decades, numerous professionals, including musicians, psychologists, and neuroscientists, have been interested in the relationship between music, the brain, and musical abilities (Flohr and Hodges, 2006). This interest is also motivated by the fact that multimodal musical stimulation during the preschool stage has broad positive repercussions on academic and social development (Gorey, 2001), as demonstrated by the results presented by Reynolds and Ou (2010). Their study attests to the long-term benefits of such stimulation, such as a higher level of academic readiness and a lower predisposition to drug addiction and criminality. Considering that music therapy interventions are designed to improve people's living conditions, whether cognitive, physical, emotional, or social, the advances in the clinical field of music therapy are not surprising, especially in the area of musical psychology, which highlights research on brain plasticity promoted by music (Gruhn and Rauscher, 2006).

Following this line, authors such as Dahmen and King (2007) and de Villers-Sidani et al. (2008) have demonstrated the influence of auditory experience on early brain development. Furthermore, authors like Schlaug et al. (1995) have provided evidence for a thicker corpus callosum in individuals who received some form of musical training before the age of 7, which allows for a greater speed of transfer between both hemispheres. This assertion has been subsequently supported by authors such as Justel and Díaz (2012), Strait et al. (2015), and Cheung et al. (2017), whose studies proved that individuals who have exercised the cerebral cortex through musical practice have developed a greater cortical volume, implying an improvement in cognitive functions.

Moreover, Hutchinson et al. (2003) observed that, depending on musical training (daily hours dedicated throughout the lifespan), the size of the cerebellum varies, tending to increase in volume. Thus, Schlaug et al. (2005) compared the biological structures between children aged 9 and 11 who played an instrument for four years, with a group that differed in instrumental practice, and found the following: the first group had a larger volume of grey matter in the sensorimotor cortex and in the bilateral occipital lobe. Other studies conducted by Hyde et al. (2009) and Hyde et al. (2010) demonstrated changes in brain areas of subjects who had received musical training, such as an increase in the volume of the corpus callosum, the right precentral gyrus, and the right primary auditory area.

Finally, Gordon et al. (2018) state that the auditory cortex is not only activated in musical perception, but also that other areas of the motor cortex are involved in the process. Indeed, Elbert et al. (1995) demonstrated the responsiveness in the left-hand movements of musicians through a magnetoencephalography (MEG) study. Consequently, many current investigations opt to study both the short-term and long-term benefits of music therapy interventions.

METHOD

Search Strategy

Regarding literature selection, the majority of the search was conducted through scientific databases recommended by the AMTA for research purposes. The primary databases utilised were: PubMed and Medline for reviewing medical-scientific articles specialising in brain function and, specifically, auditory processing; Web of Science (WoS), Dialnet, and Google Scholar.

Physical bibliographic materials, acquired through previous bibliographical research, were also consulted. This included books published by various authors such as Sloboda (1985) and Colwell (2006). Similarly, it was necessary to consult medical manuals available through various university databases. Thus, the literature reviewed primarily consists of bibliographic materials, with secondary sources predominating, having consulted studies conducted by various researchers.

For the search, the keywords used were "music and brain" and "music therapy". These terms were searched in multiple languages, specifically English and Spanish, employing the Boolean operator "and" to combine them. Furthermore, the number of search results was reviewed, with titles and abstracts of the retrieved articles, documents, and research studies being read to select those aligning with the search criteria.

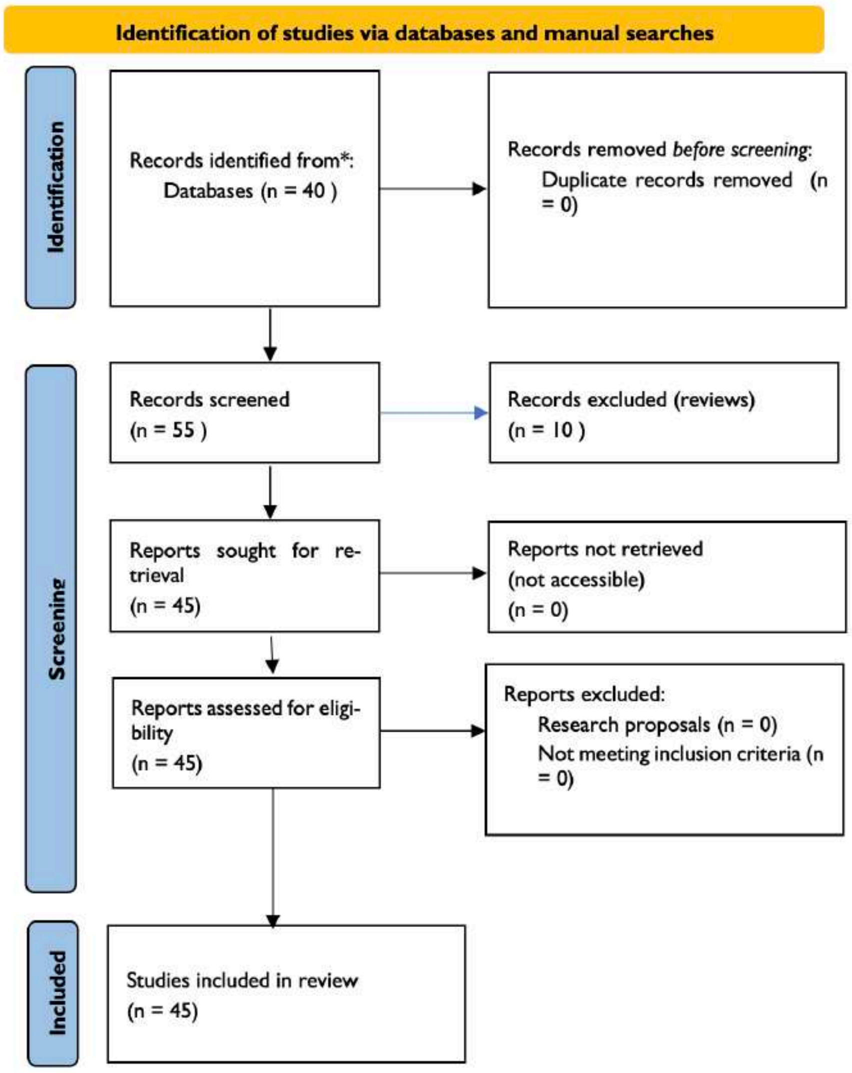
Inclusion and Exclusion Criteria

The primary criterion for literature selection was the year of publication. This literature review is thus predominantly based on articles, journals, books, and research conducted between 2019 and 2024, aiming to incorporate information obtained in recent years and considering the scientific and technological advancements that have, as observed in many references, enabled the investigation of aspects not apparent in earlier documents.

However, it is important to note that, despite setting this criterion, it was not feasible to adhere to it globally. Consequently, books and research over twenty years old were included, always striving to ensure that these did not exceed the percentage of publications from the last five years. This is because, as will be discussed in the limitations section, there is a limited number of publications related to this topic. Therefore, the second inclusion criterion was the relevance of the consulted publications to our research, particularly for

Figure 1

PRISMA Flow Diagram



Note: Developed by the authors based on Haddaway et al. (2022).

authors referenced in subsequent studies, making them potentially essential for substantiating the review.

Finally, another criterion employed for the inclusion or exclusion of literature was its impact, i.e., whether it was a publication with numerous citations in subsequent works. Publications older than ten years and those that did not influence subsequent research due to a lack of scientific rigour were excluded. Similarly, the exclusion criterion related to access and visibility of articles was applied; thus, those that could not be fully reviewed or for which direct access was unavailable were not included in this literature review.

The selection of literature resulting from the application of these criteria will be presented in a PRISMA flow diagram, illustrating the various strategies and mechanisms used for article selection.

Regarding the procedure for data selection, extraction, and management, based on the PRISMA protocol, it is important to note the following: data deemed relevant for our research were extracted from the consulted bibliography in a standardised manner. The fields included were: author(s), year, type of publication (article, book, manual, etc.), participants (for research studies that required them), and their main ideas summarised. We exported the search results into a table formatted according to APA 7th edition style.

Results of Study Selection

A total of 45 studies were deemed eligible for inclusion in the present literature review. The articles included in this review were published between 1936 and 2024, with 17.78% of the studies originating from the last ten years.

Table 1

List of References Meeting Inclusion Criteria

Cite	Country	Title	Study design	Participants	Main ideas
Abrahan y Justel (2014)	Argentina	Musical Improvisation:A Shared Perspective from Music Therapy and Neurosciences.	Literature Review	Not relevant	Increased Study of the Neurobiology of Music. Music places unique demands on the nervous system. Musical improvisation as a creative behaviour. The importance of music therapy. The theoretical development and application of neurorehabilitation.
Altenmüller (2001)	Germany	How many music centers are in the brain.	Literature Review	Not relevant	Localisation of Musical Centres. Neural Plasticity in Response to Musical Experience. Evolutionary and Cultural Aspects. Connections between Brain Areas. Clinical and Therapeutic Implications.
Andrade y Bhattacharya (2003)	Brasil	Brain turned to music.	Systematic Review	Not relevant	Brain Processing of Music and Neural Plasticity. Emotional and Cognitive Effects of Music. Therapeutic Applications of Music.
Arias (2014)	Spain	Music and the Brain: Neuromusicology.	Literature Review	Not relevant	Procesamiento cerebral de la música y plasticidad neuronal. Efectos emocionales y cognitivos de la música. Aplicaciones clínicas y terapéuticas de la música.

Table 1 (cont.)

List of References Meeting Inclusion Criteria

Cite	Country	Title	Study design	Participants	Main ideas
Besson y Schön (2001)	EEUU	Comparison between Language and Music.	Literature Review	Not relevant	Neurological Foundations of Language and Music. Temporal, Structural, and Cerebral Plasticity Aspects Associated with Both Processes. Cognitive and Emotional Functions of the Processes. Clinical and Educational Implications.
Bever y Chiarello (1974)	EEUU	Cerebral dominance in musicians and nonmusicians.	A observational study	Musicians and not Musicians chosen based on their age and gender, educational level and medical history and Health status	Brain dominance: the comparison between musicians and non-musicians. Theoretical and practical implications of brain plasticity, brain dominance and music education.
Blair y Shimp (1992)	EEUU	Consequences of an unpleasant experience with music: a second-order negative conditioning perspective.	Experimental reseaarch	Participants (limited access to information)	The consequences of unpleasant musical experiences. Emotional and cognitive associations derived from music.
Cheung et al. (2017)	Hong Kong	Music training is associated with cortical synchronization reflected in EEF coherence during verbal memory encoding.	Experimental reseaarch	60 participants (30 with Training instrumental and 30 No training instrumental). All right-handed and No Record of problems neurological or psychiatric.	Association between music training and cortical synchronization. Verbal memory encoding. Importance of neuronal plasticity. Implications for education and cognition.
Custodio y Cano-Campos (2017)	Perú	Efectos de la música sobre las funciones cognitivas.	Literature Review	Not relevant	Impact of music on memory, attention and concentration. Effects on executive function. Cognitive benefits in childhood and old age. Underlying mechanisms and therapeutic applications.
Davies (1978)	UK	The psychology of music.	Literature Review	Not relevant	Musical perception. Emotional response to music. Social and cultural functions of music. Music and cognition. Therapeutic applications of music.

Table 1 (cont.)

List of References Meeting Inclusion Criteria

Cite	Country	Title	Study design	Participants	Main ideas
Díaz (2010)	México	Music, language and emotion: a cerebral approach	Literature Review	Not relevant	Interaction between music and the brain. Effects of music on language. Emotional aspects of music.
Flohr y Hogdes (2006)	UK	Music and Neuroscience.	Literature Review	Not relevant	The neurological bases of music processing. Neural plasticity and musical learning. The impact of music on the brain and emotion. Music and cognitive development. The clinical and therapeutic applications of music.
Grabrielsson y Lindström (2001)	Suecia	*The influence of musical structure on emotional expression.*	Experimental reseaarch	Not relevant	Structural characteristics of music and its impact on emotional expression. Cultural and individual perception. Implications for composition and performance.
Gil-Loyzaga (2005)	España	Structure and function of the auditory cortex. Bases of the ascending auditory pathway.	Literature Review	Not relevant	Anatomy of the auditory cortex. Tonotopic organization of the auditory cortex. Ascending auditory pathway.
González (2020)	Colombia	What makes the brain dance.	Literature Review	Not relevant	Impact of dance on brain activity. Cognitive and emotional benefits of dancing. Neuroscientific and psychological aspects of dance. Dance as an educational tool.
Gruhn y Rauscher (2006)	EEUU	Music and Neuroscience.	Literature Review	Not relevant	Cognitive and emotional effects of music. Brain processing of music. Brain plasticity in relation to music. Therapeutic implications.
Hutchinson et al. (2003)	United States	Cerebelar volume of musicians.	Comparative observational study	Two groups of men and Women categorized as musicians and not musicians.	The significant differences in cerebellar volume between musicians and non-musicians. The positive correlation with the intensity of music training.

Table 1 (cont.)

List of References Meeting Inclusion Criteria

Cite	Country	Title	Study design	Participants	Main ideas
Hyde et al. (2009)	Canadá	Musical training shapes structural brain development.	Longitudinal Observational Study	Two groups of participants divided into musicians and not musicians. The group formed by musician consisted of 15 children; and the control group, of 16 children.	Evidence of structural changes in specific regions of the brain. Brain plasticity. Impact of early onset of music training. Educational and clinical implications.
Hyde et al. (2010)	Canadá	The effects of musical training on structural brain development: A longitudinal study.	Longitudinal Study	Information not provided.	Impact of musical practice on the brain. Brain plasticity and adaptation. Educational and therapeutic implications.
Jauset-Berrocal (2013)	España	Música y neurociencia: Un paso más en el conocimiento del ser humano.	Literature Review	Not relevant	Impact of music on the brain. Brain plasticity and music. The brain processing of music. Cognitive and emotional development. Educational and therapeutic aspects.
Justel y Díaz (2012)	España	Plasticidad cerebral: participación del entrenamiento musical.	Literature Review	Not relevant	Definition and concept of brain plasticity. The effects of music training on the brain. Practical and educational applications.
Koelsch (2005)	Alemania	Toward a neural basis of music perception.	Literature Review	Not relevant	The neural bases of musical perception. Emotional and cognitive responses to music. Interactions between auditory areas. The clinical and educational implications.
Koelsch (2009)	Alemania	A Neuroscientific Perspective on Music Therapy.	Literature Review	Not relevant	The neurobiological bases of music therapy. The scientific evidence of the effects of music. The mechanisms of action of music in the brain. Clinical and therapeutic applications.
Langer and Ochse (2006)	Germany	The neural basis of pitch and harmony in the auditory system.	Theoretical review	Not applicable	The neural processing of pitch and harmony. Neural coding mechanisms. The interactions between auditory and cognitive processing.

Table 1 (cont.)

List of References Meeting Inclusion Criteria

Cite	Country	Title	Study design	Participants	Main ideas
Lerdhal y Jackendoff (1996)	EEUU	A generative theory of tonal music, reissue, with a new preface.	Literature Review	Not relevant	The generative theory of tonal music. The structures and cognitive processes involved. The relationship between music and language.
Levitin (2006)	EEUU	This is your brain on music: the science of a human obsession.	Literature Review	Not relevant	Auditory perception and musical structure. Neuroscience and musical emotions. Musical memory. The effects of music on the brain and mental health.
Lewis (2002)	Reino Unido	Musical minds.	Literature Review	Not relevant	The psychology of musical perception. Musical memory. The link between music and emotions. The cognitive and neurological aspects of musical perception.
Liégeois-Chauvel et al. (1998)	Francia	Contribution of different areas in the temporal lobes to music processing.	Experimental reseaarch	65 patients with Cortectomy Temporary unilateral and 24 participants with Controls normal	The location of brain areas activated during music processing. The differentiated functions of brain structures in the face of musical processing. The specific roles of brain areas in musical perception.
Lozano et al. (2013)	México	The brain and music.	Literature Review	Not relevant	The neurological effects of music. Brain activation by music.
Martínez (s.f.)	Argentina	Music processing in the cerebral hemispheres: a preliminary study.	Literature Review	Not relevant	Benefits of music processing. The presence of music in everyday life. Musicality as a cognitive capacity. The complexity of the music-brain relationship.
Mikutta et al. (2014)	Suiza	Professional musicians listen differently to music.	A comparative study	Musicians fans and professionals.	The differences in music listening between professional musicians and non-musicians. The cognitive and emotional processing of music.
Montalvo and Moreira-Vera (2016)	Ecuador	The Brain and Music.	Theoretical review	Not applicable	The interaction between music and the brain from a neurological perspective. The neurocognitive and emotional effects of music. The neuro-biological mechanisms of musical response. Clinical and therapeutic applications.

Table 1 (cont.)

List of References Meeting Inclusion Criteria

Cite	Country	Title	Study design	Participants	Main ideas
Palacios y Olaya (2023)	Colombia	El maravilloso impacto de la música en el cerebro.	Literature Review	Not relevant	The impact of music on the brain. The cognitive and emotional aspects of music. Therapeutic and educational applications.
Pantev et al. (1998)	Germany	Increased auditory cortical representations in musicians.	A comparative observational study	Participants divided into two groups according to their Features: musicians and not musicians	The increase in auditory cortical representations in musicians. The impact of musical practice on the brain. The implications for brain plasticity.
Platel et al. (1997)	France	The structural components of music perception: a functional anatomical study	Experimental reseaarch	6 participants trained with the type of stimuli and tasks to be performed	The location of the brain areas activated during music listening. The cognitive and emotional functions involved in musical perception.
Raffman (1993)	EEUU	Language, music and mind.	Literature Review	Not relevant	The comparison between language and music. The cognitive and perceptual aspects. Emotion and expression.
Schellenberg et al. (2007)	UK	Exposure to music and cognitive performance: test of children and adults.	Experimental reseaarch	144 participants divided into two groups: children (between 10 and 11 years old) and adults (20 years old)	The effects of music on cognitive performance. The differences in the effects of music between children and adults: the influence of age on the way music affects cognitive skills.
Schlaug et al. (1995)	Alemania	Increased corpus callosum size in musicians.	A comparative observational study	30 professional musicians and 30 non-musicians (control group) of the same age, sex and skill	Changes in the size of the corpus callosum in musicians. The structural changes in the brain that facilitate communication between the two hemispheres. Brain plasticity induced by musical practice.
Sloboda (1985)	UK	The Musical Mind: The Cognitive Psychology of Music.	Theoretical review	Not applicable	Musical perception. Musical development. Music and emotions. Musical creativity.
Soria-Urios et al. (2011)	Spain	Music and the brain (III): brain evidence of musical training.	Theoretical review	Not applicable	The effects of music training on the brain. Brain plasticity. The clinical and educational implications.

Table 1 (cont.)

List of References Meeting Inclusion Criteria

Cite	Country	Title	Study design	Participants	Main ideas
Storr (2002)	UK	*Music and the mind.*	Literature Review	Not relevant	Music as emotional expression. The therapeutic effects of music. Psychological and musical development. Creativity and musical composition. Neuroscience and musical perception.
Tramo (2001)	EEUU	Music of the hemispheres.	Literature Review	Not relevant	The differentiated effects on the cerebral hemispheres. Cortical and subcortical processing. Functional and emotional asymmetry.
Trehub (2004)	EEUU	Music Perception in Infancy.	Literature Review	Not relevant	The early development of musical perception. Musical preferences in childhood. Emotional responses to music. The implications for early music education.
Zatorre (2005)	UK	Music, the foog of neuroscience?	Literature Review	Not relevant	The exploration of music and neuroscience: the relationship between music and brain function.

Note: Source: Authors' own.

RESULTS

Interventions

This section will analyse the articles included in the literature review. The PRISMA flow diagram visually illustrates the steps followed for the selection of included articles and those that were, conversely, excluded as previously stated. This diagram was generated using the tool developed by Haddaway et al. (2022). Key aspects of this diagram are as follows:

- Four databases were used: PubMed, Dialnet, Google Scholar, and Scielo, yielding 75 studies.
- All 75 retrieved articles were reviewed, and 20 studies were automatically excluded due to a lack of access.
- Finally, 45 articles were utilised, with 10 articles not meeting the inclusion criteria.

Methodological Aspects

All consulted studies and articles had diverse research objectives. Consequently, the different types of designs employed became evident for analysis. Thus, concerning the design of the included bibliography, the following points are noteworthy:

The literature review included 45 studies, investigations, and articles: 66.67% (30 studies) employed a theoretical design, a category which included theoretical, systematic, and bibliographic reviews. Regarding the different types of study designs, it is important to mention the prevalence of experimental studies (5 studies), accounting for 11.11% of the included investigations.

Limitations in the Reviewed Studies

During the selection process, we encountered the following limitations: poor suitability of studies with respect to the topic, inaccessible full texts, and the limited relevance of some research.

DISCUSSION

This review has examined various research and/or popular science articles on the relationship between music and the brain. Although initially there appears to be existing research in this field, there is a notable lack of updated and accessible literature, particularly publications after 2020, that corroborate and investigate phenomena using new technologies such as functional magnetic resonance imaging (fMRI), positron emission tomography (PET), and neurophysiology (magnetoencephalography). Thus, it would be highly advantageous to have studies that specify the differences in musical auditory processing between individuals with specific musical training and those without.

Furthermore, there is a dearth of accessible information regarding the biological structures comprising the auditory system. Consequently, most of the articles cited in relation to this topic are medical textbooks, such as García-Porrero and Hurlé (2020) and Lalwani (2018), which can pose a challenge to comprehension. Finally, concerning the meanings of music, Davies (1978) asserted that meaning acquired significance based on the listening context. However, Sloboda (1985) outlined various factors influencing the assignment of meaning to a musical work: circumstances, musical or linguistic knowledge, etc.

Suggestions

1. Employ novel technologies to investigate the effects of music on the brain, such as cerebral activation, plasticity, and neural adaptation, observable through medical imaging techniques like PET scans and magnetic resonance imaging.
   Research into the effects of music on the brain should leverage the latest technological advancements in neuroscience to yield more precise and detailed results. Technologies such as positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) enable observation of how different types of music affect specific brain areas, both in terms of activation and long-term structural changes. These advancements facilitate the identification of neural activation patterns associated with emotions, memory, creativity, or cognitive processes, potentially leading to innovative music-based therapies for neurological and psychological disorders. Furthermore, the use of real-time neuroimaging tools can allow for the observation of cerebral plasticity—the brain's capacity to reorganise and adapt to specific musical stimuli—with implications for both neurological rehabilitation and music education.

2. Conduct current research to confirm or refute initial hypotheses from older studies which, at present, continue to form the basis of all forthcoming research, in order to ensure updated bibliography. Many theories and approaches used in contemporary research are founded on earlier studies which, although pioneering at the time, might be based on outdated methodologies or incomplete data. Therefore, it is crucial to undertake new research to review, confirm, or refute the fundamental assumptions of previous studies, to assess whether the conclusions remain valid in the current context. The constant review and updating of bibliography is essential, not only to improve the precision and validity of existing theories, but also to provide a solid foundation for future studies. Moreover, this fosters the evolution of the sciences, as it allows research methods to adapt to current technological and scientific advancements. This is the case with Davies' (1978) theory known as "Darling, they're playing our tune!" and the theories proposed by Sloboda (1985).

3. Specify the scope of research to define and delimit the topic.
   A common challenge in scientific research is the broadness and vagueness of study topics. To avoid scattering efforts across a multitude of irrelevant aspects, it is fundamental to clearly specify the scope of the investigation. Defining a clear and precise focus enables researchers to concentrate on key areas and obtain more concrete and significant results. This delimitation can be based on aspects such as the target population (e.g., children, older adults, patients with neurological diseases), the type of music

(classical music, popular music, therapeutic music, etc.), or the specific effects to be analysed (memory improvement, stress reduction, emotional changes). By narrowing the topic in this manner, the design of more controlled and exhaustive studies is facilitated, reducing the risk of bias and increasing the relevance of the findings.

Limitations and Future Prospects

The present literature review has some limitations related to its theoretical framework; the main limitation being the absence of articles published in years subsequent to 2020. Thus, as mentioned in the methodology, it was necessary to utilise older research, some even more than 20 years old, due to its relevance to the investigated topic.

Furthermore, we should have accessed other databases that would have allowed us to gain access to restricted articles, enabling the inclusion of more recent studies, in terms of their publication year, and thereby adding other perspectives from different authors. Some of these unutilised databases that could have been employed include: Dadun, Scrib, and Cochrane Register; whereas the preferred scientific databases were: PubMed, Dialnet, Google Scholar, and Scielo.

Thus, most of the limitations experienced are related to the publication years of the analysed studies, with a constant need for future research that delves deeper into the existing relationship between music and the brain; that is, the processes that occur in the brain areas linked to listening to a musical work.

CONCLUSIONS

The conclusions drawn from this literature review on the relationship between music and brain function, as well as its impact on music therapy, are presented below. Based on the analysis of various studies, the following key points are highlighted:

- Influence of music on brain function. This literature review confirms that music has a significant impact on the human brain, particularly in auditory processing, neural plasticity, and emotional and cognitive regulation. Different brain areas, including the auditory cortex, the limbic system, and the motor cortex, actively participate in interpreting and responding to musical stimuli.

- Lack of updated literature. Despite a substantial body of research on the topic, a scarcity of recent and accessible literature has been identified, especially post-2020. This underscores the need for new research utilising advanced technologies, such as functional magnetic resonance imaging (fMRI) and positron emission tomography (PET), to explore the effects of music on brain activity in greater depth.

- Effectiveness of music therapy. Evidence suggests that music therapy offers extensive benefits in clinical and educational settings, positively influencing neurological rehabilitation, the improvement of cognitive functions, and emotional well-being. However, continued research is recommended to measure the long-term effects of music therapy interventions.

- Impact of musical training on brain plasticity. Various studies have demonstrated that musical training can induce structural changes in the brain, fostering neural plasticity and improving interhemispheric communication. This reinforces the relevance of music in cognitive development and its application in educational and therapeutic environments.

- Need for specific and delimited research. The importance of precisely defining the scope of studies on music and the brain is emphasised. Future research should focus on specific populations (such as children, older adults, or patients with neurological disorders) and analyse the differentiated effects of various musical genres on the brain.

In conclusion, this literature review highlights the fundamental role of music in brain function and neurological rehabilitation. Nevertheless, new research integrating neuroimaging technologies and more precise experimental approaches is required to confirm and expand knowledge on this relationship. Furthermore, greater specificity in future studies is recommended to optimise the impact and application of music therapy in different domains.

Generative AI Statement

The authors declare that no Generative AI was used in the creation of this manuscript.

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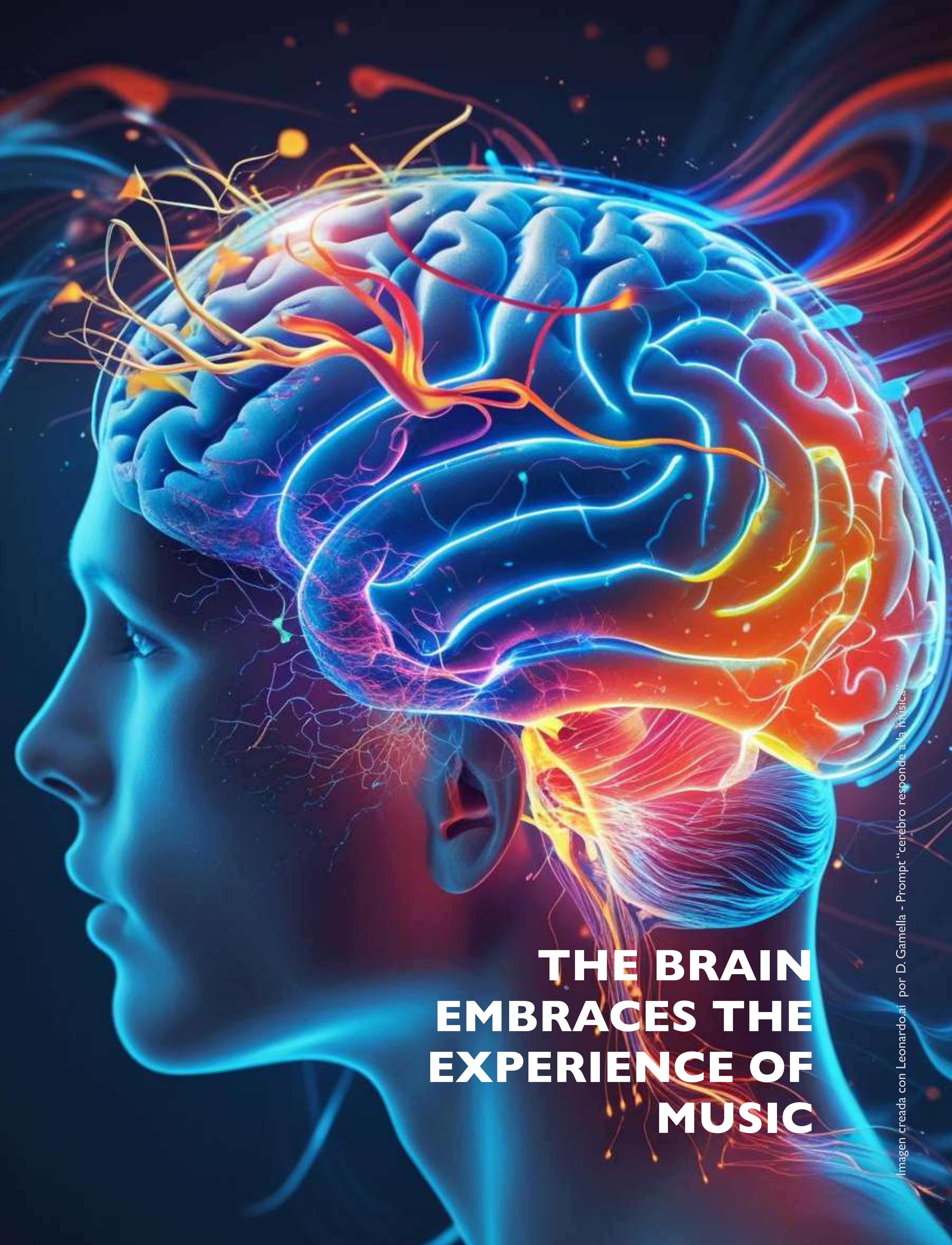

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